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Wind erosion risk in agricultural soils under different tillage systems in the semiarid Pampas of Argentina

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ABSTRACT

The effect of plant residues, plant canopy and non-erodible soil aggregates on wind erosion has been mostly evaluated under controlled wind tunnel conditions. Little is known about their combined effect under field conditions. Wheat of different growth lengths are widely cropped in the semiarid Pampas of Argentina (SAP) under different tillage systems. Aim of this study was to measure the soil cover in wheat types of different growth lengths, cropped under three tillage systems, and their effects on wind erosion in a semiarid environment of Argentina. Measurements of the soil coverage with crops canopy, stubble and soil aggregates were done 15 days each during a wet (2005) and a dry (2006) year on a sandy loam Entic Haplustoll of the semiarid Pampas. On the basis of climatic and soil coverage data wind erosion was estimated with the Revised Wind Erosion Equation (RWEQ). Results showed that wind erosion was lower in no-till (NT) than in vertical- (VT) or conventional tillage (CT) in all wheat types due to high soil coverage with plant residues (83% of total soil cover during fallow). In contrast, during fallow in CT and VT, a 16% of soil was covered with non-erodible aggregates (64% of total cover) and plant residues (32%). As a result, the hazard of wind erosion was high in CT and VT (899 and 1002 kg ha^{-1}, respectively). Regarding the wheat types, wind erosion amounts of CT and VT were, in average of both sampling years, lower in long cycle wheat (LCW, 635 kg ha^{-1}) than in intermediate cycle wheat (ICW, 980 kg ha^{-1}) and short cycle wheat (SCW, 1237 kg ha^{-1}). The higher wind erosion of SCW was produced by the simultaneous occurrence of minimum soil coverage and high climatic erosivity just after crop seeding. In NT wind erosion was low in all cases (between 0 and 31 kg ha^{-1}). However, high wind erosion amounts (1500 kg ha^{-1}) can occur in NT after crop seeding. SCW cropped with CT and VT must be avoided in the studied region, in order to make an efficient wind erosion control. No-till was the best system for controlling wind erosion, though, moderate wind erosion amounts can occur in this system during short periods of time after seeding of all wheat types.

1. Introduction

Wind erosion is an important soil degradation process in arid and semiarid regions of the world (Peterson et al., 2006), including the semiarid Pampas of Argentina (SAP) (Buschiazzo et al., 1999). In cultivated fields wind erosion depends mostly on the soil coverage with plant canopy or plant residues and on the soil surface roughness produced by tillage practices. The effectiveness of these parameters in controlling wind erosion has been mostly quantified separately and under controlled conditions (Fryrear, 1984; Bilbro and Fryrear, 1994; Armbrust and Bilbro, 1997). Little is known about their combined effect under natural field conditions.

Soil coverage of 30% with plant residues or canopy is effective in controlling wind erosion, since this soil coverage lying residues control 70% of wind erosion and crops canopy a 90% (Fryrear et al., 1998). Nevertheless, other authors stated that wind erosion control effectivity depends on crop type, management system and climatic conditions (Mendez and Buschiazzo, 2008). In some regions it can be seen that the susceptibility of the soil to wind erosion during winter crops fallows is high (López et al., 2003). Therefore, small grain crops like wheat are important in these systems for controlling wind erosion (Krupinsky et al., 2007).

Wheat is an important crop in the semiarid Argentinian Pampas (SAP) (REPAGRO, 2005), where it is seeded at different dates and cropped under different tillage systems (Buschiazzo, 2006). Little is know about the wind erosion risk of different wheat canopies and tillage systems on wind erosion in SAP.

The available models to predict wind erosion, like the Revised Wind Erosion Equation (Fryrear et al., 1998) or the Wind Erosion Prediction Model (Hagen, 1991), include crop subroutines for

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wheat with spring and winter wheats. Such wheat types do not have the same growth habits than wheat cropped in the semiarid Pampas and other parts of the world.

NT has been mostly described as an efficient system in controlling wind erosion because it left a large amount of plant residues on the soil surface (Thorne et al., 2003; Merrill et al., 2004). Though, these authors showed that after wheat seeding a short period with high soil susceptibility to wind erosion existed, even in NT. Tillage systems which include residue removal with ploughs can leave the soil bare but rough by the formation of clods. This can occur mostly in the fallow and during plant emergence. A question can be therefore stated regarding the efficiency of each tillage system in controlling wind erosion.

It is known that plant residues provide an effective control of wind erosion, but their temporal variation with time, as a function of seasonal climatic changes, and its relation to wind control efficiency provided by plant canopy and clods formed by ploughs which increase the soil surface roughness, have been less studied. According to that it is expected that wind erosion will be mostly controlled by plant residues in NT and by soil aggregates in tillage systems where the soil is disturbed. Wind erosion control will be more efficient in NT than in the other tillage systems.

The aim of this paper was to evaluate the amount of soil cover under variable wheat types and different tillage systems and its effects on wind erosion amounts.

2. Materials and methods

This study was carried out in a long-term tillage experiment developed since 1996 in the Faculty of Agronomy of the University of La Pampa, Argentina (S36°46′; W64°16′; 210 m a.s.l.). The mean annual precipitation of this semiarid study site is 764 mm and the mean annual temperature is 15.5 °C for the period 1971–2001. Prevailing winds blow from the North and the South, with higher speeds and gusts up to 60 km h^{-1} during the spring and the summer (Casagrande and Vergara, 1996). The soil of the studied site was an Entic Haplustoll with an A horizon containing 2.37% organic matter, 12.8% clay, 62.0% sand, 25.2% free lime, pH of 6 and P (extractable Bray) 19 mg kg^{-1}.

Measurements of soil cover were carried out on three 4.5 ha plots, each submitted to conventional tillage (CT), vertical tillage (VT) and no-tillage (NT). Before experiment starts, all plots were planted with sunflower (*Helianthus annus*) which was harvested in March 2005 and 2006. Weeds were controlled with disk in CT and with disk and chisel in VT. Weeds were always controlled with herbicides in NT (Glifosate and 2–4 d) and after wheat seeding in VT and CT.

Each 4.5 ha plot was divided into three 1.5 ha subplots. In each subplot a different wheat type was seeded: long cycle wheat (LCW), intermediate cycle wheat (ICW) and short cycle wheat (SCW). The combination of three tillage systems and three wheat types produced nine treatments.

In each treatment the soil coverage with plant rests (including stubble mulch and weed rests), wheat canopy, weeds (living weeds) and non-erodible aggregates (greater than 10 mm in diameter) were measured each 15 days by triplicate during 2005 and 2006.

Soil cover was measured by means of digital photographs of the soil surface, taken in different moments since fallow start and wheat growth. The photographs were randomly taken at each sampling subplot from three 1 m^2 soil surfaces, perpendicularly to the soil surface from 1.5 m height. The Paint Shop Pro 7 PC program was used to determine the soil coverage as follows: each digital photograph was divided into a 4 cm × 4 cm grid in the PC screen, producing a total of 126 crossing points; the percentage of soil cover was then determined as the quotient between the number of crossing points with flat residues, non-erodible aggregates, weed and canopy cover and the total amount of crossing points of the grid.

A meteorological station was installed close to the experimental field in order to register wind speed at 2 m height, as well as air temperature and precipitation. Based on the averaged wind speeds, monthly temperatures and rains, the climatic erosivity of the Wind Erosion Equation represented by the *C*-factor, which combines the effect of monthly rains and temperatures of a given region, was calculated (WEQ, Woodruff and Siddoway, 1965) (Eq. (1)). Such data are listed in detail in Table 1.

Wind erosion was estimated with the stand alone version of RWEQ (Fryrear et al., 1998), developed by Zobeck (personal communication) in an Excel spreadsheet. This model was found to be adequate to predict wind erosion in the semiarid Pampas of Argentina (Buschiazzo and Zobeck, 2008).

$$C\text{-factor} = 386\left[\frac{U^3}{((P/2.54)/(1.8T+32))^{10/9}}\right] \tag{1}$$

where U is the mean monthly wind speed at 10 m height expressed in m s^{-1}, P is the mean monthly precipitation expressed in mm and T is the mean monthly temperature expressed in °C.

Wind erosion was calculated for each individual storm and treatment by loading the model with the following information: contents of soil organic matter, clay, silt, and, one minute wind speed averages (m s^{-1}) and soil coverage with plant residues, wheat canopy, weeds and non-erodible aggregates. The humidity factor was 1 in all cases and no erosion was calculated during the first three days after a rain event. Wind erosion amounts were calculated for periods of time when wind speeds were higher than 5 m s^{-1} at 2 m height, the threshold wind velocity considered by RWEQ (Fryrear et al., 1998).

The wind value considered by the RWEQ was calculated with Eq. (2) for each single storm.

$$W = \sum_{i=1}^{N} U_2(U_2 - U_t)^2 \tag{2}$$

Table 1
Main climatic conditions during the sampling periods.

	Year	April	May	June	July	August	September	Total	Mean
Temperature (°C)	2005	14.7	10.9	8.4	8.5	9.7	11.9	–	10.7
	2006	16.1	10.1	9.2	5.7	10.4	13.1	–	10.8
Precipitation (mm)	2005	0.2	29.3	20.9	6.8	13.6	58.4	129	–
	2006	28	0.4	2.4	1.8	0	23.6	56	–
Wind speed at 2 m height (m s^{-1})	2005	2.1	1.5	1.0	2.2	2.4	3.0	–	2.1
	2006	1.3	3.4	2.9	3.3	3.8	3.9	–	3.1
C-factor	2005	17.0	7.1	1.9	20.6	27.4	50.6	–	20.7
	2006	3.9	73.6	45.3	66.5	105.1	109.8	–	67.4

where W is the wind value, U_2 is the wind speed at 2 m height expressed in m s^{-1} and U_t is the threshold wind velocity at 2 m height expressed in m s^{-1}.

Eq. (3) was used for calculating the soil loss ratio (SLR) in the stand alone version of RWEQ. This equation was developed by Mendez and Buschiazzo (2008) for the conditions of the semiarid Pampas:

$$\mathrm{SLR_f} = \mathrm{e}^{-0.0605 \times \mathrm{SC}} \quad (3)$$

where $\mathrm{SLR_f}$ is the soil loss ratio for lying residues and SC the soil coverage with lying residues.

Results were analyzed with ANOVA, mean comparison tests (LSD) and multivariate analysis (correspondence analysis).

3. Results and discussion

3.1. Soil coverage

The total soil coverage was higher in NT (74.8%) than in CT (34.5%) and VT (33.7%) in all wheat types along all the sampling period of both studied years ($p < 0.05$) (Fig. 1).

Total soil coverage varied differently with time in each tillage system with a general increase from the first- to the last sampling dates in CT and VT, and a minimum soil coverage by the half of the sampling period in NT. In CT and VT, this behavior was produced by the maintenance of low soil coverage with plant residues due to tillage operations during the fallow, and by increasing wheat canopy coverage at advanced sampling dates. These results allowed to differentiate two sampling periods with different soil cover composition: the fallow period, when the soil coverage was mainly produced by plant residues (NT) and non-erodible aggregates (CT and VT), and post-seeding period of wheat, when the soil coverage was mainly produced by wheat canopy.

During the fallow period, most of the soil coverage of CT and VT was produced by non-erodible aggregates (64% of the total coverage as average of both studied years and wheat types) and the rest by plant residues. However, with respect to non-erodible aggregates, the cover was lower in 2005 (20%) than in 2006 (26%). This difference was related with the occurrence of rains before the disk operation carried out at the start of fallowing, which increased soil moisture: in 2005, only 0.6 mm fell 15 days before tilling, remaining the soil dry; in 2006, 56 mm fell 7 days before tilling increasing the soil moisture. It is known that the ploughing of dry soil destroys aggregates in coarse textured soils and that tilling of relatively wet soils can form large clods (Tisdall and Adem, 1986; Barzegar et al., 1995).

A correspondence analysis showed that, during the fallow, the CT and VT was more associated to soil coverage with non-erodible aggregates (Fig. 2). These results can be attributed to the incorporation of plant residues into the soil and to the formation of non-erodible aggregates during tillage operations. It is known that tillage buries residues and can form clods (Lampurlanés and Cantero-Martínez, 2006). The lack of tillage during the fallow period of NT produced constant and high soil coverage in all treatments and sampling years (between 42 and 90%), but the presence of non-erodible aggregates was negligible (0–6%). The correspondence analysis showed that NT was associated with the soil residue coverage during the fallow (Fig. 2). Thorne et al. (2003) demonstrated that the soil surface roughness contributed less to the total soil surface coverage in NT. López et al. (2003) and Lampurlanés and Cantero-Martínez (2006) found that the random roughness covered a 5% of the soil surface in NT, a similar value than in our study.

In NT, sunflower residues covered between 1.5 and 7% of the soil surface during the fallow of all wheat types and studied years, while the total soil coverage was, in average, 78%. Most of the soil coverage during this period was produced by residues of *Eleusine indica*, a weed which invaded sunflower during its late growth stages and was controlled with herbicides. These results indicated that weeds can contribute to cover the soil and to reduce its susceptibility to wind erosion, particularly after the harvest of sunflower. Bedmar et al. (2000) demonstrated that sunflower productivity was not affected by weed invasion when it occurred 40 days after emergency. Therefore, a strategy to prevent wind erosion after the harvest of sunflower, a crop which left very low residue amounts on the soil surface (Mendez, 2009), is the use of herbicides with low residual effect at sunflower planting. This may allow high soil coverage after sunflower harvest without affecting crop productivity.

In 2005, the total soil coverage of NT during the fallow period decreased with time due to the stubble decomposition. In 2006 this tendency was opposite due to the unexpected growth of weeds, which increased the soil coverage until 21 April. At this date weeds were controlled with herbicides and their rests maintained the total soil coverage constant until the seeding of wheat. After wheat seeding in 2005, the total soil coverage of CT and VT remained unchanged (LCW to ICW) and in some cases it increased (SCW). In 2006 it decreased always, following the evolution of the non-erodible aggregates. At this same time, the non-erodible aggregates coverage under these treatments remained unchanged in LCW and ICW and increased in SCW. In this case, the amount of rains before the seeding operation was relatively high (between 7 and 27 mm). In contrast, in 2006 the soil coverage with non-erodible aggregates decreased as a consequence of the low rains (0–3 mm) occurred 30 days before the seeding operation. These results agree with those of Merrill et al. (1999).

In NT, the soil remained highly covered all along the studied period, excepting after wheat seeding, when the seeder lowered plant residues and total soil coverage dropped to 50–65%. Guy and Lauver (2006) and Merrill et al. (2006) reported similar and even lower soil coverage percentages after wheat seeding on dry pea, lentil and sunflower residues. López et al. (2003) found that in a dry environment of Spain the soil coverage after the seeding of barley in a NT system dropped to 15–20%. These results indicate that the total soil coverage during the fallow period, and in some cases after seeding, were low in CT and VT in all wheat types and studied years (not higher than 30%). This indicates that both tillage systems left the soil scarcely protected and susceptible to be eroded by wind in this period, independent of the wheat type. No measurable effects of seeding operation on aggregates amounts were found in this tillage system.

3.2. Wind erosion estimations

The RWEQ-estimated wind erosion varied between 5 and 1817 kg ha^{-1} (Table 2). These amounts were lower than those calculated with the RWEQ by Merrill et al. (1999) for a silt loam soil of US (5–23,000 kg ha^{-1}). The difference can be due to the larger fallow period of the rotation studied by Merrill et al. (1999) (2 years vs. 3 months) and to the dryer conditions during their study (429 mm year^{-1} vs.520 mm year^{-1} in both years).

The averaged wind erosion for all wheat treatments and both years were much higher in CT (899 kg ha^{-1}) and VT (1002 kg ha^{-1}) than in NT (13 kg ha^{-1}) ($p < 0.05$; Table 2). These results are probably due to the higher soil coverage with plant residues on NT than on both CT and VT (Fig. 1). Similar results were found by Merrill et al. (1999), López et al. (2003) and Thorne et al. (2003).

In average for all wheat types and tillage systems, estimated wind erosion was slightly lower in 2005 (603 kg ha^{-1}) than in 2006 (673 kg ha^{-1}). These results are in agreement with the lower climatic-factor of 2005 (20.7) than of 2006 (67.4) (Table 1). The highest *C*-factor in 2006 than in 2005 was produced by higher wind

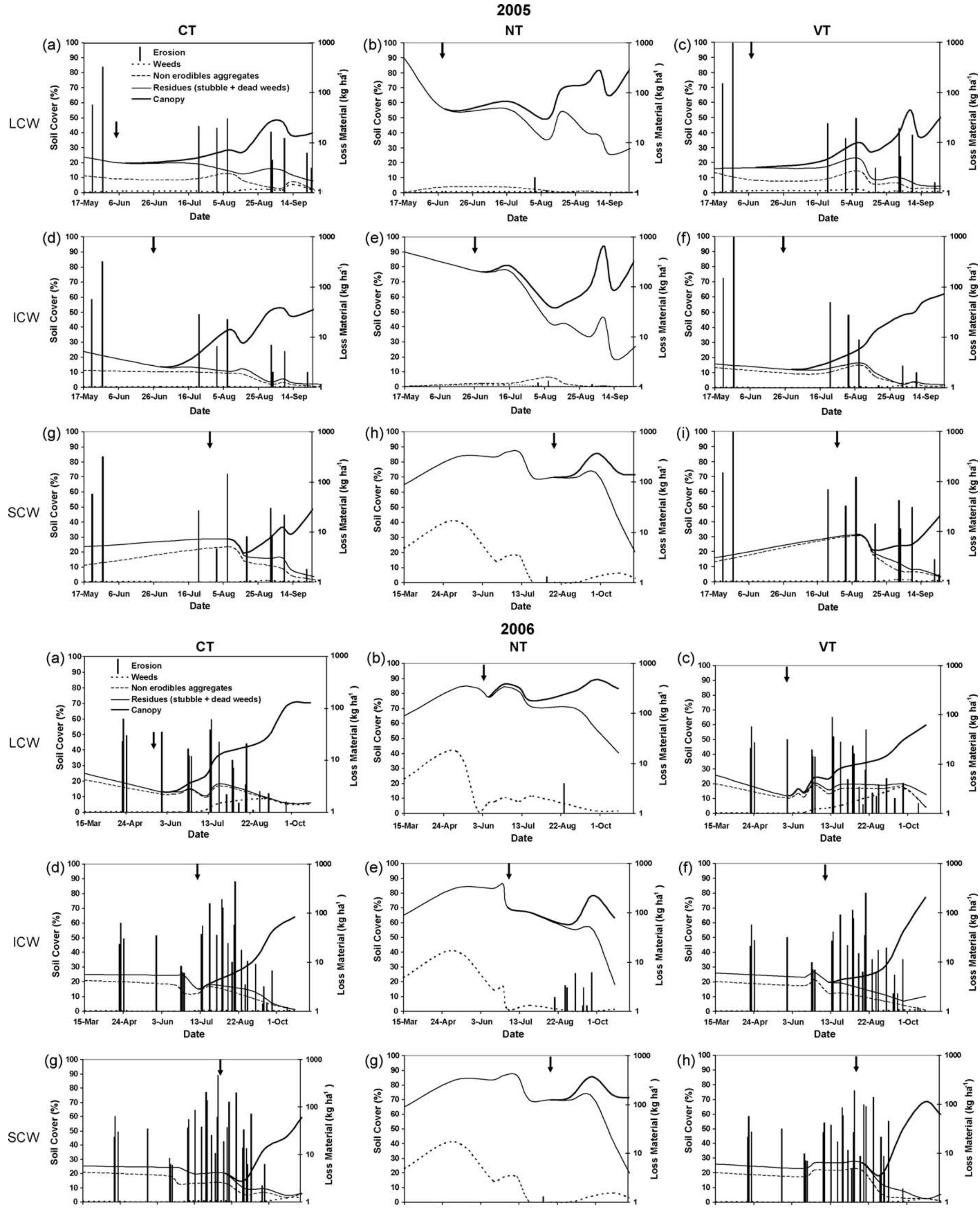

Fig. 1. Accumulated soil coverage with plant residues, non-erodible aggregates and wheat canopy in (a) CT and LCW, (b) NT and LCW, (c) VT and SCW, (d) CT and ICW, (e) NT and ICW, (f) VT and ICW, (g) CT and SCW, (h) NT and SCW, and (i) VT and SCW in 2005. Arrows indicate seeding dates. CT, conventional tillage; VT, vertical tillage; NT, no-till; LCW, large cycle wheat; ICW, intermediate cycle wheat; SCW, short cycle wheat.

Table 2
RWEQ-calculated wind erosion in three tillage systems, three different wheat-rotations, two erosion periods and two years.

Year	Erosion period	Wind erosion (kg ha^{-1})								
		CT			NT			VT		
		LCW	ICW	SCW	LCW	ICW	SCW	LCW	ICW	SCW
2005 Wet	Fallow	378	378	378	0	0	0	1100	1100	1100
	Crop growth	114	75	246	5	5	24	110	93	324
	Total	492	453	624	5	5	24	1210	1193	1424
2006 Dry	Fallow	151	262	1285	2	2	5	137	229	660
	Crop growth	220	1087	531	5	29	1	331	693	422
	Total	371	1350	1817	7	31	6	468	922	1082

CT = conventional tillage, NT = no-till, VT = vertical tillage, LCW = long cycle wheat, ICW = intermediate cycle wheat, SCW = short cycle wheat.

speeds (3.1 m s^{-1} vs. 2.1 m s^{-1} at 2 m height) and lower rains (56 mm vs. 129 mm) occurred during the measuring period (Table 1).

The highest risk of wind erosion occurred during the fallow period under CT and VT (Table 2). For this critical period, the higher soil loss estimation in 2005 than in 2006 was linked to one isolated wind storm occurred on May 29, 2005 (Fig. 1). This storm lasted 240 min and had a maximum wind speed of 15.6 m s^{-1}, producing an averaged wind value, a measure of the wind force of a given storm, of 263. This value is much higher than the historical wind value for May which is 2 for the studied region.

In 2005, the estimated erosion for the period following the wheat seeding was relatively low (between 75 and 324 kg ha^{-1}), in agreement with the moister conditions of that period (Table 1). Conversely, in 2006, wind erosion after the seeding was high (between 200 and 1087 kg ha^{-1}) due to the dry and windy climatic conditions of that period.

With respect to wheat type, estimated wind erosion amounts of CT and VT were, in average of both sampling years, lower in LCW (635 kg ha^{-1}) than in ICW (980 kg ha^{-1}) and SCW (1237 kg ha^{-1}). The highest values of SCW were produced by the simultaneous occurrence of minimum soil coverage and high climatic erosivity just after the crop seeding. Both, the soil coverage and the *C*-factor started to increase since June and showed maximum values during September. Seeding of SCW was carried out by this date.

Soil coverages after seeding of LCW and ICW were also low (Fig. 1), being the soil in this period also susceptible to wind erosion. Nevertheless, seeding was done earlier (June 6 and May 26 for LCW and June 22 and July 10 for ICW) than the occurrence of the maximum climatic erosivity (August–September), making both parameters not to coincide. That explains why LCW and ICW presented lower erosion risk after seeding than SCW. Mendez (2009) showed that the growth rate of early seeded wheats (LCW) is slower than that of late seeded wheat (SCW). This author suggests that SCW will cover the soil faster than LCW, being, therefore, more effective in controlling wind erosion. Present results show that, though its faster growth, SCW are less effective in controlling wind erosion due to the occurrence of high climatic erosivity after seeding when the soil cover is low.

Under NT estimated wind erosion was low in all cases (0–31 kg ha^{-1}). The highest soil loss was calculated for the period following wheat seeding, in agreement with soil coverages close to 50% (Fig. 1). Merrill et al. (1999) also showed that the seeding operation in NT systems can decrease the soil coverage up to 50%, increasing drastically the risk of wind erosion. Though risk of erosion was low for the climatic conditions of this study, predictions made with RWEQ demonstrated that wind erosion amounts can reach values up to 1500 kg ha^{-1} when wind speeds exceed 16.5 m s^{-1}. This loss exceeds the tolerable wind erosion amounts found by Verheijen et al. (2009) which vary between 300 and 1400 kg ha^{-1}. Such result demonstrated that wind erosion can also occur in NT when extremely windy conditions are given in this region. Merrill et al. (2004) found that a silty loam soil under sunflower stubble and managed with NT was subjected to considerable wind erosion when high-energy windstorm events occurred.

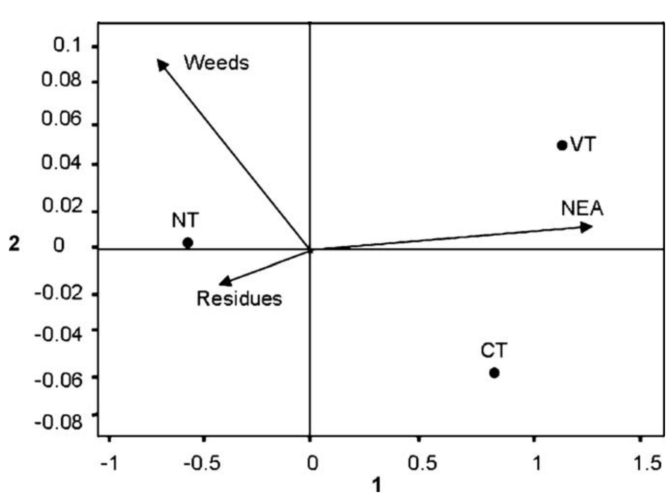

Figure 2. Correspondence analysis for type of soil coverage during the fallow and tillage systems. NEA, non-erodible aggregates; CT, conventional tillage; VT, vertical tillage; NT, no-till.

4. Conclusions

Higher soil surface cover under no-till (NT) than in vertical- (VT) or conventional tillage (CT) explain the lower risk of wind erosion in agricultural soils under NT in the semiarid Pampas of Argentina. Most of this soil cover during fallow is due to plant residues (83% of total coverage). In contrast, the low cover under CT and VT (average of 16%) is mainly provided by non-erodible aggregates (64% of the total coverage).

During wheat seeding, a drastic reduction of the sparse soil coverage with plant residues and the destruction of non-erodible aggregates were produced by the seeder in the VT and CT treatments. Though all wheat types showed similar trends, only the short cycle wheat (SCW) presented high wind erosion risks in this period, as the soil coverage reduction coincided with high climatic erosivities (August–September). Seeding also reduced the soil coverage in NT, but this effect seems to be critical only in the cases where soil coverage after seeding dropped to 50%, and high wind erosion amounts (wind speeds > 16.5 m s^{-1}) occurred.

No-till was the most effective system for controlling wind erosion, though, moderate wind erosion amounts can occur in this system during short periods of time after seeding of all wheat types. Short cycle wheats must be avoided in CT and VT in order to control efficiently wind erosion in the study region.

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